AD-781 176

# INSTRUMENTATED THERMAL MANNIKIN

William Elkins, et al

Acurex Corporation

Prepared for:

Aeronautical Systems Division

January 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

## NOTICE

When Government drawings, specification, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and in fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AIR FORCE/56780/24 January 1974 – 100

UNCLASSIFIED

Security Classification

AD-781 176

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

1. ORIGINATING ACTIVITY (Corporate author)

Aerotherm Division/Acurex Corporation
485 Clyde Avenue
Mountain View, California 94042

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

Instrumented Thermal Mannikin

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

William Elkins
James G. Thompson

6. REPORT DATE

January 1973

7a. TOTAL NO. OF PAGES

47 57

7b. NO. OF REFS

-

8a. CONTRACT OR GRANT NO.

F33657-71-C-1179

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

Technical Report ASD-TR-73-33

10. DISTRIBUTION STATEMENT

Approved for public release: distribution unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Deputy for Subsystems
Aeronautical Systems Division
Air Force Systems Command
Wright Patterson Air Force Base, Ohio

13. ABSTRACT


This report covers the development, fabrication and testing of an advanced instrumented mannikin system. The mannikin system consists of the following elements:

- A rugged mannikin shell which can withstand high temperature (1800°F for six seconds), can be easily cleaned, and is modularized for simple replacement of the components.
- An inexpensive sensor which provides accurate time-temperature histories which are converted to sensor surface heat flux prediction required to compute human skin burn assessments.
- A compact data acquisition system which reliably and accurately obtains and stores data from all 124 mannikin sensors
- A versatile mannikin support system used to: charge mannikin on-board batteries, checkout the mannikin prior to test runs; and transfer and confirm data after test runs.
- An accurate and easily used computer code which allows assessment of burn damage by depth and severity of burn for individual locations, body regions and the total body excluding the head, hands, and feet.




DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

UNCLASSIFIED

Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Instrumented Mannikin<br>Fire Burn Assessment<br>Fire Protective Clothing<br>Skim Simulant | | | | | | |

UNCLASSIFIED

Security Classification

*U.S. Government Printing Office: 1974 — 758-430/363

## FOREWORD

This report covers the development of an instrumented mannikin system for JP-4 fueled fire environment evaluation of aircrew protective clothing. This program was conducted by Aerotherm Division of Acurex Corporation under USAF Contract F33657-71-C-1179 for the AFSC Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The work was administered under the direction of the Air Force Materials Laboratory with Mr. Robert Stanton as Project Officer. This volume describes the analysis, engineering, development and testing associated with producing the end item mannikin system. The instrumented mannikin consists of:

1. Mannikin
2. Instrumentation subsystem
3. Mannikin data acquisition system
4. Mannikin support system
5. Computer code

Appendix A, Design Analysis Report, of this report is avaliable from Aeronautical Systems Division and is published separately.

Mr. William Elkins was Program Manager and Mr. James Thompson was Program Engineer.

This technical report has been reviewed and is approved.

William M. Quinn

WILLIAM M. QUINN, Colonel, USAF
Director, Life Support System Program Office
Deputy for Subsystems

## ABSTRACT


An instrumented mannikin system that is used for the evaluation of clothing when exposed to JP-4 fuel fires has been developed and proven under this program. Over 20 successful tests have been performed with the system using the Army's Natick Laboratories JP-4 fire test facility. Data relative to burn damage and fire environment never obtained before in this environment were successfully measured and processed. All major objectives of the program were met with the actual results of the testing providing more data than was expected during initial phases of the program.

The data provided by the mannikin system are an order of magnitude more detailed and quantitative than any data obtained before on this subject. Not only are 114 points of the mannikin surface used for burn damage evaluation but complete data on temperature-time history are obtained. The system obtains data which are probably more accurate than the state of knowledge on both the thermal properties of the skin and the criteria for a given burn. The major item which the mannikin brings to the testing of clothing in JP-4 fuel fire is the consistency and detail required to evaluate the relative protection provided by various fabrics. The mannikin removes the subjective evaluation required by past testing methods and moves the state of testing from an art into a very scientific evaluation.

The second advantage the system presents, which is very important and brings to the testing a potential for reduced cost, is that the data from the testing can be saved in rough form (surface heat flux) and analyzed using any burn damage criteria deemed most appropriate. The testing does not have to be performed again as better criteria for both the skin model or burn damage are obtained. All that is required is a simple change to the computer code and repeated data reduction.

In addition to the above, very important advantages, the mannikin system, now that it is developed, can be used not only for JP-4 fuel fire testing but also in many other areas where burn damage, flammability, flamespread, thermal fatigue, and cold exposure are important to evaluate. In these applications it will obtain data never available before. The total value of the system will be realized when the content of these data is used for the betterment of man and his ability to survive hostile environments.

The following major items were accomplished:

- A sensor was developed to provide accurate time-temperature histories which are converted to sensor surface heat flux predictions required to compute human skin burn assessments.
- Fire total heat flux at the level of the mannikin hands was successfully measured.
- Compact data acquisition system was developed which reliably and accurately obtains and stores data from all the 124 mannikin sensors. These data are stored on permanent records for easy access and data for each of the 124 sensors is available on an individual sensor basis.
- A rugged mannikin shell which can withstand high temperature (1800°F for 6 seconds), can be easily cleaned, and is modularized for simple replacement of the components was developed.
- An accurate and easily used computer code was developed which allows assessment of burn damage by depth and severity of burn for individual locations, body regions, and the total body excluding the head, hands and feet.

The value of the data obtained during the 20 fire pit tests has only slightly been realized. As the data are reviewed in more depth, the following information is expected to be obtained.

1) Data relative to heat flux levels inside a fire can be evaluated and the character of the fire can be more fully understood. Photographic records in combination with heat flux data can be used to better understand the fire.

2) The data from the surface temperature sensors can be evaluated on an individual basis in combination with photographic records to better understand the thermal behavior of the various types of fabrics tested. Fabric shrinkage, breakup, cooldown, and many more important factors can be evaluated.

TABLE OF CONTENTS

## LIST OF ILLUSTRATIONS

## LIST OF TABLES

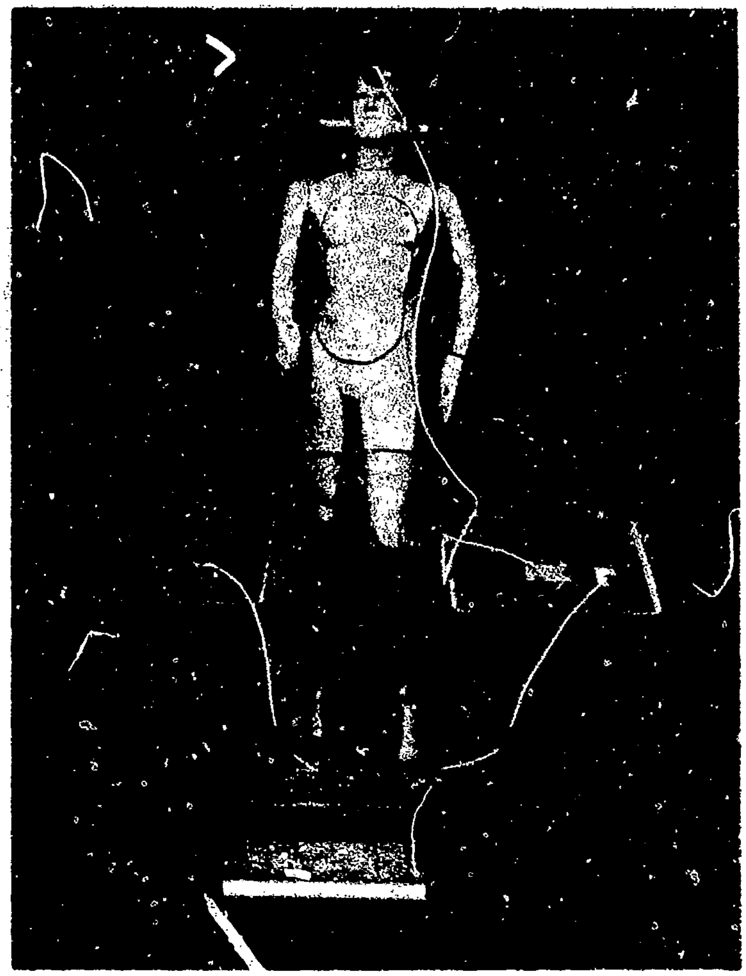

Figure 1. Total Instrumented Mannikin System

A complete description of the mannikin system is included in Appendix A, "Design Analysis Report" (DAR). A less extensive description with emphasis on the distribution of the system as it now exists follows in the main body of this report.

Section 2 briefly covers program development and addresses itself to program results while Section 3 presents future development recommendations.

## SECTION 2
## PROGRAM DEVELOPMENT

The program was initiated on July 1, 1971 and was divided into a series of dependent tasks beginning with a thorough literature search. Concurrent with the Task 1 effort, hardware design and analysis was initiated under Task 2, which was concerned with such problems as:

- Vendor source selection,
- Materials selection,
- Sensor design,
- Mannikin detail design,
- Computer code development

The program is logically divided into its four major subsystems:

1. Mannikin
2. Instrumentation
3. Data Acquisition System
4. Data Reduction and Processing.

Each subsystem interfaces with all other subsystems and therefore there is some overlap of the developmental areas of the program. Each subsystem's development is described independently and follows the literature search effort (Section 2.1) which influenced all subsystems.

### 2.1 LITERATURE SEARCH

At the beginning of the project the literature was completely reviewed to determine the state of knowledge pertaining to the items which are important to the development of the total mannikin system. The categories investigated include:

- JP-4 fuel fire expected environment.
- Past skin simulant development
- Human skin thermal physical properties for temperature predictions.
- Burn damage assessment and test data.

The literature which was reviewed on these subjects is listed in Appendix B and the results of this review are discussed extensively in that report. The results and conclusions of the literature review will be discussed more fully in the following sections of the report.

## 2.2 ENGINEERING ANALYSIS AND MANNIKIN DEVELOPMENT

### 2.2.1 Mannikin

The mannikin, appears to be a conventional clothing mannikin, but, in fact, is a carefully engineered subsystem, composed of modular elements able to meet the 100 fire exposure goal without repair; having known thermal properties, and designed to withstand unscheduled impacts without requiring repair. Further, the mannikin is designed to maintain a fixed position through all fire tests, a feature which is important for correlation of burn damage with previous and subsequent tests.

The mannikin is designed for quick turn-around with the following features:

- Uniform and identical sensors for each temperature measurement location.
- Uniform receptacles for all sensors.
- Standard thermocouple plug for sensor replacement.
- Simple and quick methods for sensor failure identification.
- Low cost sensor allowing spares for replacement of individual sensors.
- Removable arms, hands, legs, and feet for ease of dressing.
- Simple and quick data acquisition system operation.
- Teflon external coating for easy cleaning.

In the field test program time between test for an individual mannikin was less than one hour. This time is consistent with the time required for fire pit preparation between tests.

The mannikin torso has a frontal panel which is easily removed to gain access to the Mannikin Data Acquisition System (MDAS) and battery packs which are housed within the mannikin torso. There are eight individual electrical harnesses distributed throughout the interior of the mannikin. Seven of the harnesses feed individual sensor signals to the MDAS. These harnesses are connected to the following areas for ease of component replacement.

- Arms and hands (2)
- Legs (2)
- Chest Panel (1)
- Upper Torso (1)
- Lower Torso (1)

The eighth harness is routed from the MDAS to the mannikin forehead and is the service harness which is used to connect the mannikin to the mannikin support system (MSS). The following signal lines are contained in this harness:

- MDAS Lanyard Start (1)
- MDAS Power on (2)
- Battery charging (3)
- Data (4)
- Ground (1)
- Run I.D. (1)
- Rewind Command (1)
- Read Command (1)
- BOT Command (1)
- Hold Command (1)
- Open Thermocouple Command (1)
- MSS Start Command (1)

A unique support system is a portion of the head and consists of support rod which protrudes laterally through the head just forward and below the ears. The left side support arm contains a lanyard released mechanism which is used to initiate the MDAS as the mannikin moves toward the fire pit.

There are 124 sensor receptacles located at strategic areas on the surface of the mannikin. Bayonet type quick disconnects are used to retain the sensors. Sensors are easily removed for repair or replacement. Each sensor station is identified by a station number engraved on the mannikin's surface.

Arms, legs, hands, feet, head and torso are modular elements assembled through the use of 90° rotation quick disconnects. Easily replaceable shear pins are designed into the quick disconnects to protect the modules from damage in case of impact. (See Figure 1).

2.2.1.1 Materials

Because of the systems approach taken in the development of the Instrumented Mannikin, materials selection was simplified. That is, the "skin simulant" function was largely assigned to the computer code leaving the requirements for the mannikin materials largely in being, compatible with the fire environment, sufficiently rugged for field usage and designed for quick turn-around during the test cycle. The only "skin simulant" function requirements assigned to the mannikin materials were:

1) The material must have known and consistent thermal properties.

2) The wall thickness must be of sufficient dimension so that the backwall remains at a constant temperature during the fire exposure.

3) The surface temperature of the mannikin must roughly approximate that of the skin in the same environment to minimize the difference between actual skin and its effect on fabric response and the mannikin during the fire exposure.

One quarter inch thick high temperature teflon coated epoxy-glass material appeared to meet all the requirements for the mannikin shell material.

The following sources provided data sheets and, in some cases, materials for evaluation:

- Emerson Cummings
- Hysol
- Shell
- Furane
- Hexcel

Of all the materials evaluated, Hexcel epoxy combined the properties most compatible with our requirements. These properties are:

1) Room temperature set -
Although the Hexcel epoxies required a step cure up to 450°F, they set at room temperature, allowing simple and relatively inexpensive female moulds to be used.

2) Long pot life -
The pot life of the Hexcel epoxy is from 4 to 6 hours allowing sufficient working time for the layup of the mannikin.

3) High temperature -
The epoxy met the 450 - 600°F operating temperatures predicted for the mannikin surface.

4) High strength -
The epoxy exhibits a 42,000 psi compressive strength with the tensile modulus and compressive modulus of 2.27 X $10^6$ and 1.82 X $10^6$ psi respectively.

Hexcel especially formulated the epoxy for our requirements reducing normal pot life from eight hours to four and modifying viscosity of the material for better workability in the fiberglass matte layup used in the mannikin. The epoxy is Hexcel's HX990 and is a three part epoxy.

Other epoxies either required an elevated set temperature or pot lifes were too short for our requirements.

Teflon Coating

To minimize clean up time and eliminate subsequent painting of the mannikin and its sensors, (which is intolerable if accurate data is to be gathered), Aerotherm investigated the use of teflon coatings.

Fortunately, a low bake Teflon "S" in beige tint was available and proved compatible with the epoxy glass layup. Low-bake Teflon "S" cures at 450°F and that cure temperature initially caused some cracking along the seams of the legs and arms. Modification in the initial cure cycle of the shell sections alleviated, but has not totally eliminated the problem since hairline cracks are present but do not affect the performance or durability of the mannikin.

Material Testing

In order to establish material layup, impact characteristics and physical characteristics of the material after repeated elevated temperature exposure a series of tests were conducted. The first tests were accomplished to establish layup procedures, a second set of tests were conducted to establish coating and substrate durability to 100, 3-second exposures at 14 $Btu/ft^2sec$ heat flux and a subsequent test established impact characteristics.

Layup

One quarter inch thick 6 x 6 panels of glass/epoxy layup were prepared. One layup was a three ply all matte layup. The other was a glass cloth + matte layup. Both samples were cured and teflon coated with low bake, Teflon "S".

They were edge mounted and then impacted with an 8.6 lb., 4 inch diameter steel ball dropped from a height of 14 feet.

The all matte layup suffered minor damage and was selected as the laminate construction for the mannikin.

Subsequently, additional samples were prepared, heat cycled as described above and impacted. There was no significant difference between the second impact test and the first. This final test confirmed selection of the epoxy and matte layup for the mannikin.

### Sensor Receptacles

The sensor receptacles (Figure 2) which are mounted through the surface of the mannikin at 124 locations, are machined from a glass epoxy slug using the same epoxy as the mannikin shell.

### Element Connectors

The element connectors are machined from 6061-T6 aluminum. Aluminum is used for a number of metallic parts which are required for the mannikin including support arms, shear pin rollers, lanyard mechanism, MDAS support bracket, etc. All aluminum surfaces are hard anodized.

## 2.2.1.2 Thermal Design Evaluation

The literature review indicated that the expected heating to the mannikin during a JP-4 fuel fire exposure would have the following basic characteristics:

- The fire heating environment is radiation dominated with less than 20 percent of the heating coming by convection.
- The radiant heating spectrum and energy levels are that represented by a black body at the fire temperatures.
- The range in fire temperatures is 1400°F and 2000°F.
- The peak heating levels are approximately 15 to 20 Btu/ft$^2$sec (4.0 to 5.4 cal/cm$^2$sec).

The above data were used to evaluate the acceptability of the proposed materials to withstand the fire environment for a total duration of 6 seconds and to provide an acceptable back wall boundary condition to the fabric exposed to the fire environment, as compared to a fabric covering a skin surface.

The results of the analytical effort (see Appendix A, Section 2.4.2.4) demonstrated that the following conclusions can be made:

- The material to be used should be loaded with as much fiberglass as is practical in order to increase the material thermal conduction and thermal capacity. The chosen epoxy has a thermal conductivity value of $4 \times 10^{-4}$ cal/cm sec °C and thermal capacity of 0.39 cal/cc°C which are less than that of skin and the glass has a thermal conductivity value of $27 \times 10^{-4}$ cal/cm sec°C which is greater than skin. It is therefore possible with addition of glass to give a thermal conductivity nearer that of skin. An increased thermal conductivity will also reduce the extreme in surface temperature for a given exposure allowing increased exposure time before an unacceptable temperature is reached.

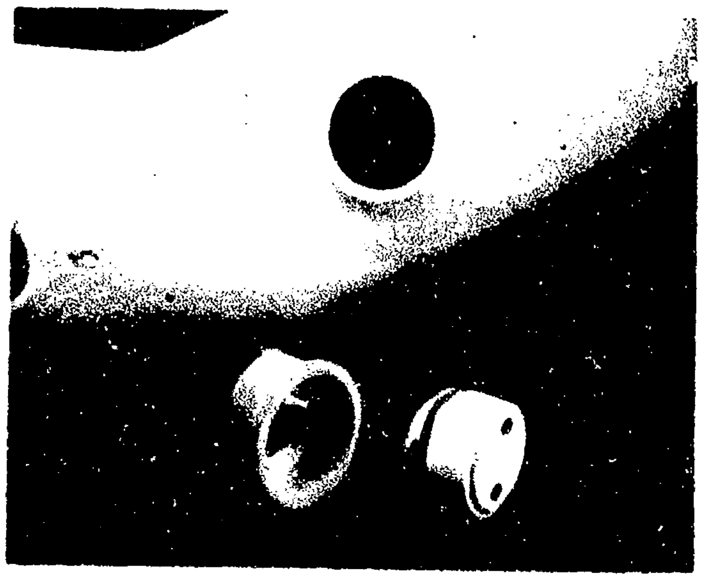

Figure 2. Sensor Receptacle

- The temperature of epoxy-fiberglass system construction will probably not exceed 500°F when exposed to the fire environment.
- The response of the constructed system will not materially effect the fabric temperature response compared to that expected when the fabric covers actual skin. It is expected that the fabric temperature would not change by more than 10°F (out of 800 to 1000°F) at the end of a normal 3 second exposure. (See Reference 87.)
- If the mannikin material is greater in thickness than approximately 0.25 inches the back wall boundary temperature will not affect the response of front surface.

This analytical conclusion plus the results of extensive material response testing have indicated that the materials chosen for the mannikin will in fact meet the system objectives.

#### 2.2.3.3 Fabrication

Three potential sources for manufacture of the mannikin were investigated. The sources were:

1. Alderson Laboratories
2. Sierra Engineering
3. Barrango Company

Both Alderson and Sierra produce highly sophisticated mannikins which are primarily for impact and medical school usage.

Barrango manufactures clothing mannikins which are more appropriate to this application.

By minor modification to Barrango tooling and processes, Barrango could manufacture the basic mannikin shells for Aerotherm. Barrango was therefore selected as the subcontractor and an initial contract was let which had as its goal, the familiarization of Barrango with the materials and layup techniques essential for the quality manufacture of the thermal mannikin.

The initial contract was let to Barrango in August of 1971 and, in addition to the requirement for flat test panels, a complete [illegible] sub-assembly was to be manufactured and a paper maché mannikin was to be supplied to Aerotherm.

Flat panels were manufactured using both glass matte and glass matte and glass cloth reenforcement. Impact tests of the completed 6 inch by 6 inch panels led to the selection of an all matte layup. Thermal analysis prior to these test panels being manufactured established the 1/4 inch thickness for both the panels and the actual mannikin.

The arm assembly would assure us of Barrango's capability to manufacture a complete mannikin using the materials and processes developed. Further, the arm would provide the Man-Systems Laboratory personnel with their first mannikin subassembly for installation of sensor receptacles, teflon coating, wire harness installation, etc., and give us a tool for refining our manufacturing and assembly procedures.

A paper mache mannikin, size 40 R, was provided and was used at Aerotherm for establishing the distribution and numbers of sensor stations required.

These sensor locations were noted on the paper mache mannikin and it was returned to Barrango for manufacture of the master moulds. The paper mache mannikin was modified by providing 1 1/2 inch diameter flats at each sensor station which were blended into the normal surface. Master female moulds were prepared from the paper mache mannikin and these were used in the manufacture of the two thermal mannikins.

The uncured mannikin elements were received at Aerotherm and each flat area (sensor station) was drilled out for installation of the sensor receptacle. The holes also provided a convenient means of inspection of the mannikin for wall thickness, delamination, etc., prior to the bonding of each sensor receptacle in place.

Element connectors were cleaned of any surplus epoxy. The front panel was cut from the torso; all latches and alignment blocks were installed and the MDAS bracket installation subplate was installed. The entire assembly was then cured over a 12-hour step cure, with the highest temperature reaching 450°F.

Final Assembly

The first mannikin was received from Barrango through the month of March and April and was completed in June. The number 2 mannikin was completed in early July and both mannikins were available for test at Natick, Massachusetts the week of July 10, 1972.

### 2.2.1.4 Sensor Distribution

As proposed, the mannikin would have had fifty instrumentation sites, each site containing one or more sensors. With sixteen square feet of body area covered by the instrumentation (the head and feet are not instrumented) this would provide only one sensor for each 45 square inches of skin area. Since the thermal conductivity of the epoxy glass (and human skin) is very low the data from one sensor (which is essentially one point averaging) covering that much area might not be indicative of the actual skin damage over the area covered. A paper mache mannikin, which was later used as the model for the fabrication of the master moulds, was used to empirically layout a reasonable distribution of sensors.

The total number established was 114 thermocouple type burn damage sensors and 10 gardon gauge sensors giving approximately 19 square inches of area for each sensor. Further these sensors were distributed over the high and low point contours and therefore should give data which has a high correlation with actual burn damage. Figures 3, 4, 5, and 6 show the distribution of sensors on the paper mache mannikin.

The sensors were assigned to all mannikin elements except the non-instrumented head, and feet, ("hands" were to be wedged shaped elements containing gardon gauges type instrumentation for measuring both total heat flux and radiation heat flux of the fire).

Sensor assignment are as follows:

| ELEMENT | NO. OF SENSORS | CHANNEL NO'S. |
|---|---|---|
| Left Arm | 10 | 1 - 10 |
| Left Hand | 4 (1) | 11 - 14 |
| Right Arm | 10 | 15 - 24 |
| Right Hand | 4 (1) | 25 - 28 |
| Left Leg | 16 | 29 - 44 |
| Right Leg | 16 | 45 - 60 |
| Chest Panel | 12 | 61 - 72 |
| Front Torso | 25 | 73 - 97 |
| Rear Torso | 27 (2) | 98 - 124 |

2.2.1.5 Element Connectors

The field tests to which the mannikin is exposed imposes requirements for ruggedness and compatibility to rough handling as well as compatibility to the fire environment.

Observation of actual tests at Natick convinced Aerotherm personnel that the following characteristics must be incorporated in the mannikin:

1. Ease of clean-up.
2. Resistance to impact damage.
3. Consistent position from test to test.

These general requirements led to specific requirements for the element connectors:

(1) Gardon gauge for fire environment measurement.

(2) Two channels 104, 106 on the rear torso are gardon gauges.

1. Detent to one repeatable position.

2. Impact release with designed shear point.

3. Shear point failure before failure of epoxy glass structure or connector/bond interface.

4. Easily connected or disconnected without the use of special tools.

5. Ease of replacement of failed shear pins.

A bayonet type disconnect was designed using two roller pins on the male portion which engage, through a slot, two ramps on the female side (see Figure 7). The roller pins have a designed groove which will fail at 900 pound per roller load. Pins are easily replaceable through the use of snap ring retention devices.

The connector was tested on a simulated arm and designed to fail at 2g impact. Initial tests failed below the design point and modifications were made and subsequent testing proved successful.

### 2.2.2 Instrumentation

The instrumentation used on the mannikin system as discussed above consisted of basically three types.

- Mannikin material surface temperature measurement with copper/constantan thermocouples.
- Total heat flux measurement with gardon gauge type heat flux gauges.
- Radiant heat flux measurement with gardon gauges using a Ca F window.

#### 2.2.2.1 Mannikin Sensor

The mannikin temperature sensor of which there are 114 distributed over the mannikin surface, is designed to measure surface heat flux. This heat flux measurement is accomplished by measurement of surface temperature on a material of known thermal properties. The sensor is designed with a thickness greater than 1/4 inch such that backwall temperature conditions will not affect the response of the surface measurements or that the sensor, for the exposure durations considered, is assumed to be of infinite extent. This assumption reduces the complexity of the data reduction tasks and the thickness dictated by structural consideration is also consistent with the assumption. The basic design of the sensor is shown in Figure 8. The sensor consists of an epoxy-glass body on which is mounted an .005 inch diameter copper/constantan thermocouple. The sensor has an overcoat of 1 to 2 mils of teflon for protection and

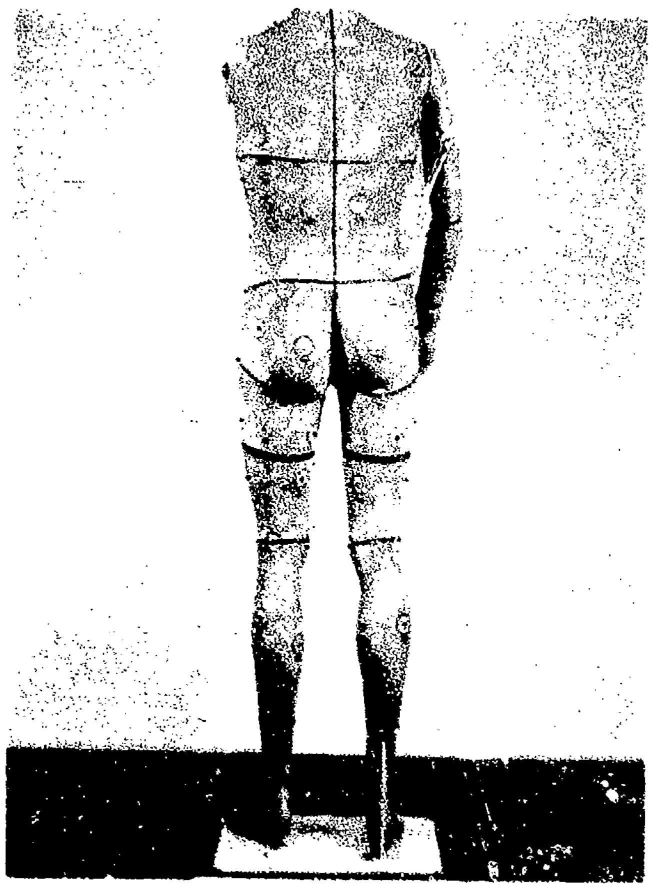

Figure 3. Instrumented Mannikin

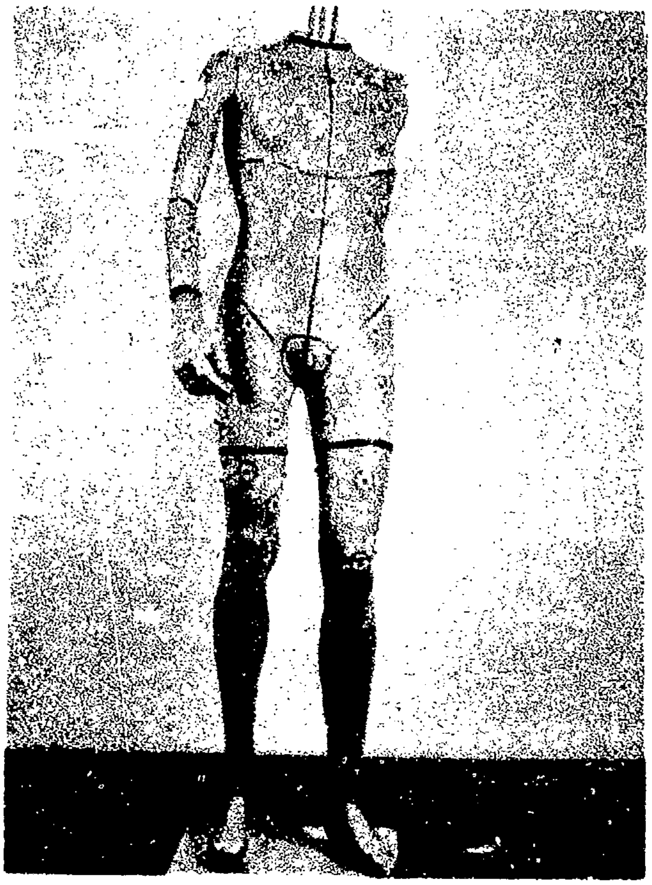

Figure 4. Instrumented Mannikin

Figure 5. Instrumented Mannikin

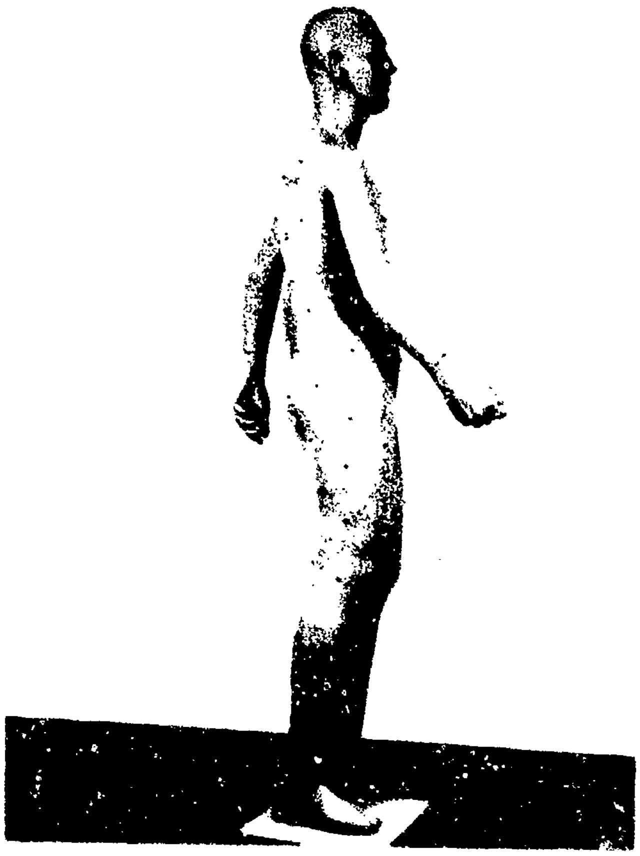

Figure 6. Instrumented Mannikin

Figure 7. Element Connector

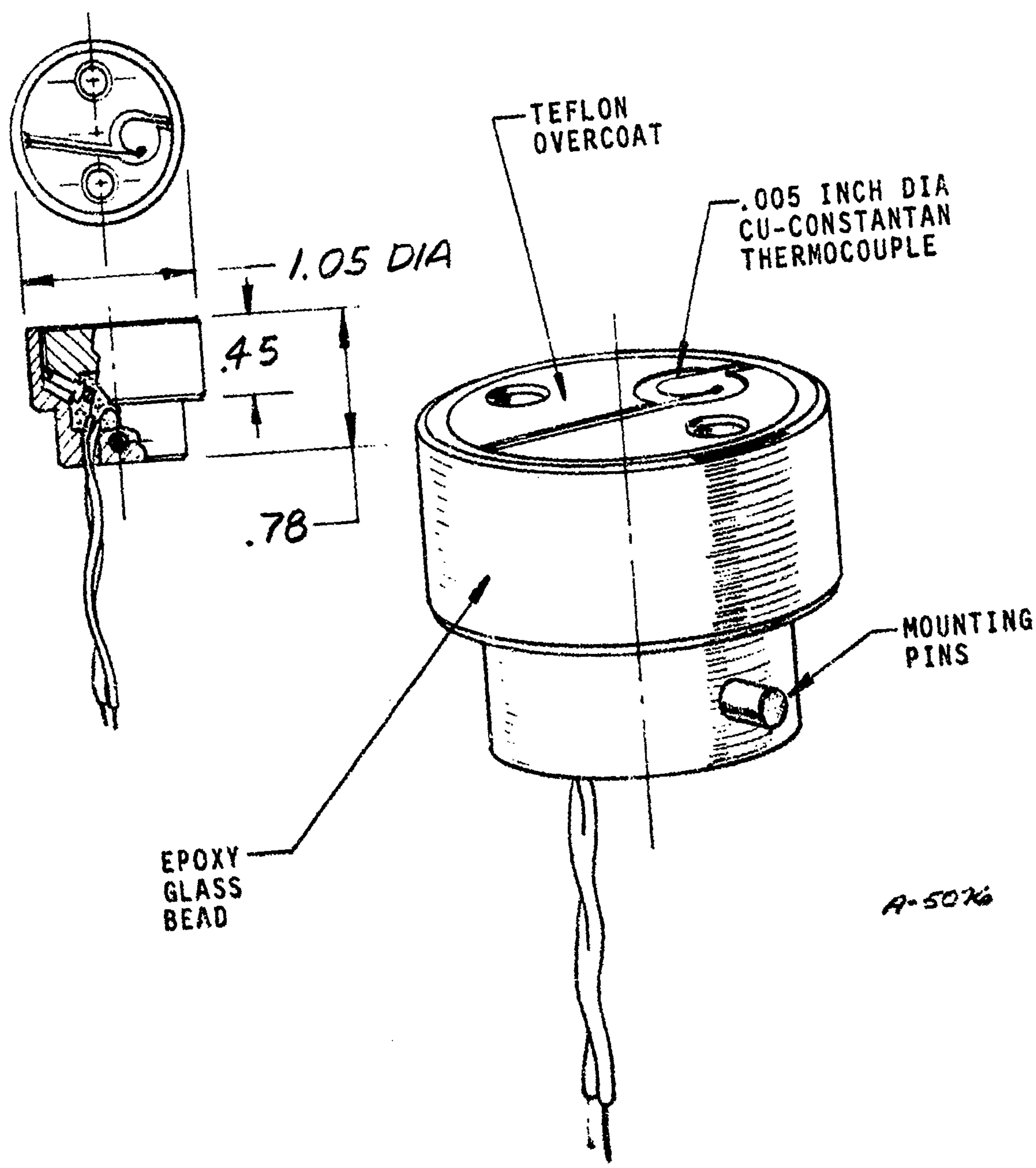


Figure 8. Mannikin Sensor Design

ease of cleaning. The thermocouple lead wires are mounted on the surface of the sensor in order to insure that the leads are mounted on an isotherm and therefore lead wire conduction errors are kept to a minimum. The thermocouple junction is mounted at one edge of the substrate in order to obtain the one inch length of copper wire required to reduce lead wire conduction to an acceptable level. Test results have shown for the above design that the effective thermocouple measurement depth is approxmately 0.004 inches.

The analysis and testing efforts required to verify the sensor design and to measure sensor thermal properties are completely described in the attached Design Analysis Report (Appendix A). Topics discussed in the above report are:

- Thermal response verification
- Sensor fabrication techniques
- Sensor repeatability
- Sensor thermal property measurement

Typical temperature test data obtained during a 3 second fire exposure are shown in the attached figures 9, 10, 11, and 12. These data show the range of response experienced during a given run. As is shown in Figure 10 the temperature of the sensor increases only approximately 25°F with a very slow decay in temperature after the 3 second exposure. The results presented in the other three figures shown behavior where temperatures at the surface exceed 250°F. Also shown in these figures are the predicted variation of skin temperature as a result of the temperature time histories. The skin temperature data was obtained using the analytical model described in Reference 87. The difference shown between the measured data and predicted skin temperatures is caused by the variations in thermal properties of the sensor compared to skin. This result however does not materially effect the response of the fabric cover to be evaluated.

2.2.2.2 Total Heat Flux Sensors

Seven total heat flux sensors are used on the mannikin. Six of these sensors (gardon gauge) are mounted on the hands to measure the heating environment of the fire. This sensor is of the gardon type and conforms to the configuration shown in Figure 13. The gardon type gauges were chosen for the following reasons:

- Compatibility of signal levels with other instrumentation.
- Linear response with heat flux for ease of data reduction.
- Fast response (time constant approximately 0.4 seconds).

A complete review of all types of heat flux instrumentation was performed and the results of this investigation are summarized in the Design Analysis Report.

A typical heat flux exposure history as a function of time for an exposure of 3 seconds is shown in Figure 14. The results show that before and after exposure,

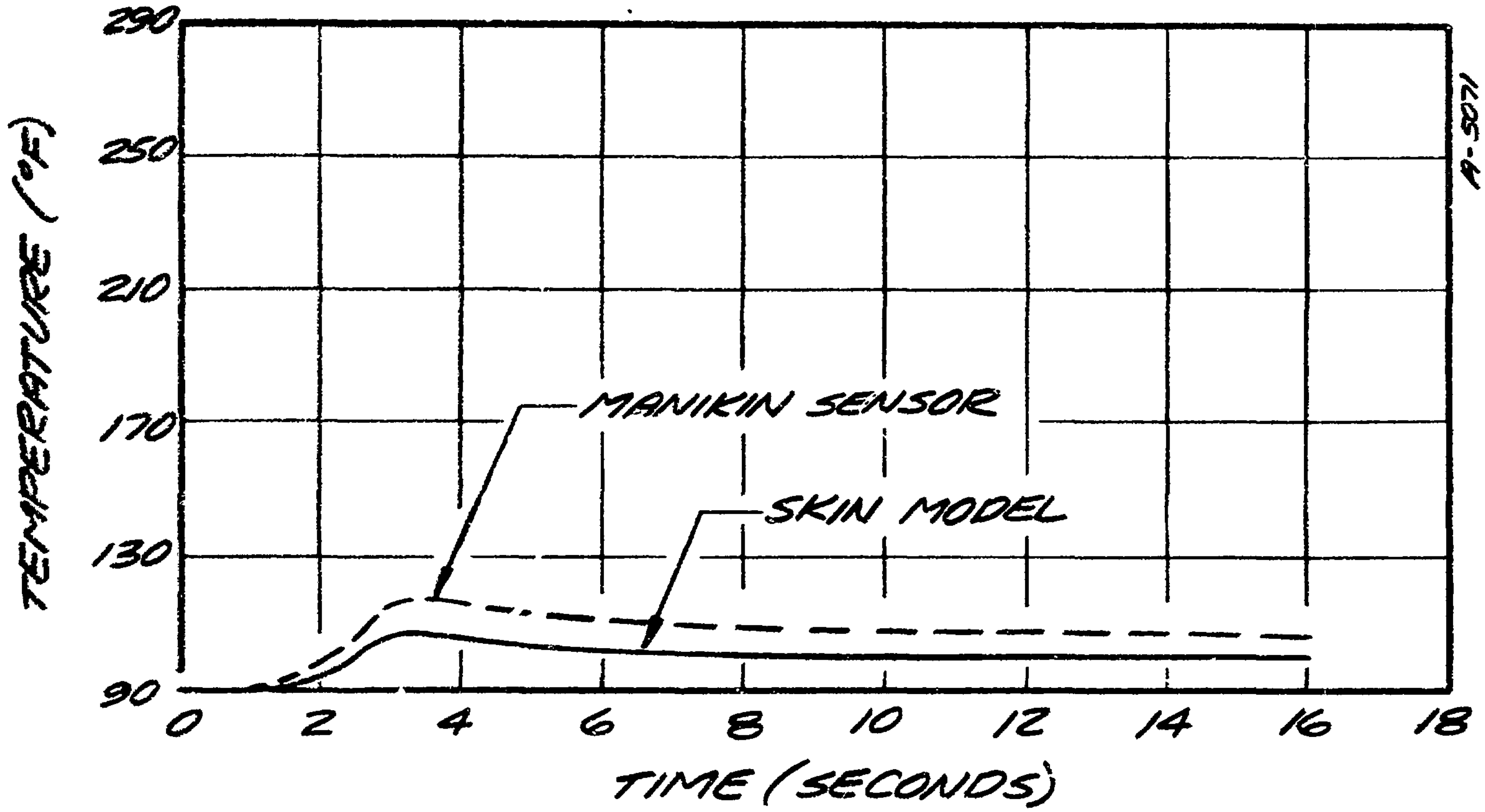


Figure 9. Mannikin Sensor Number 61 - Test Data Upper Right Front Torso - No Damage

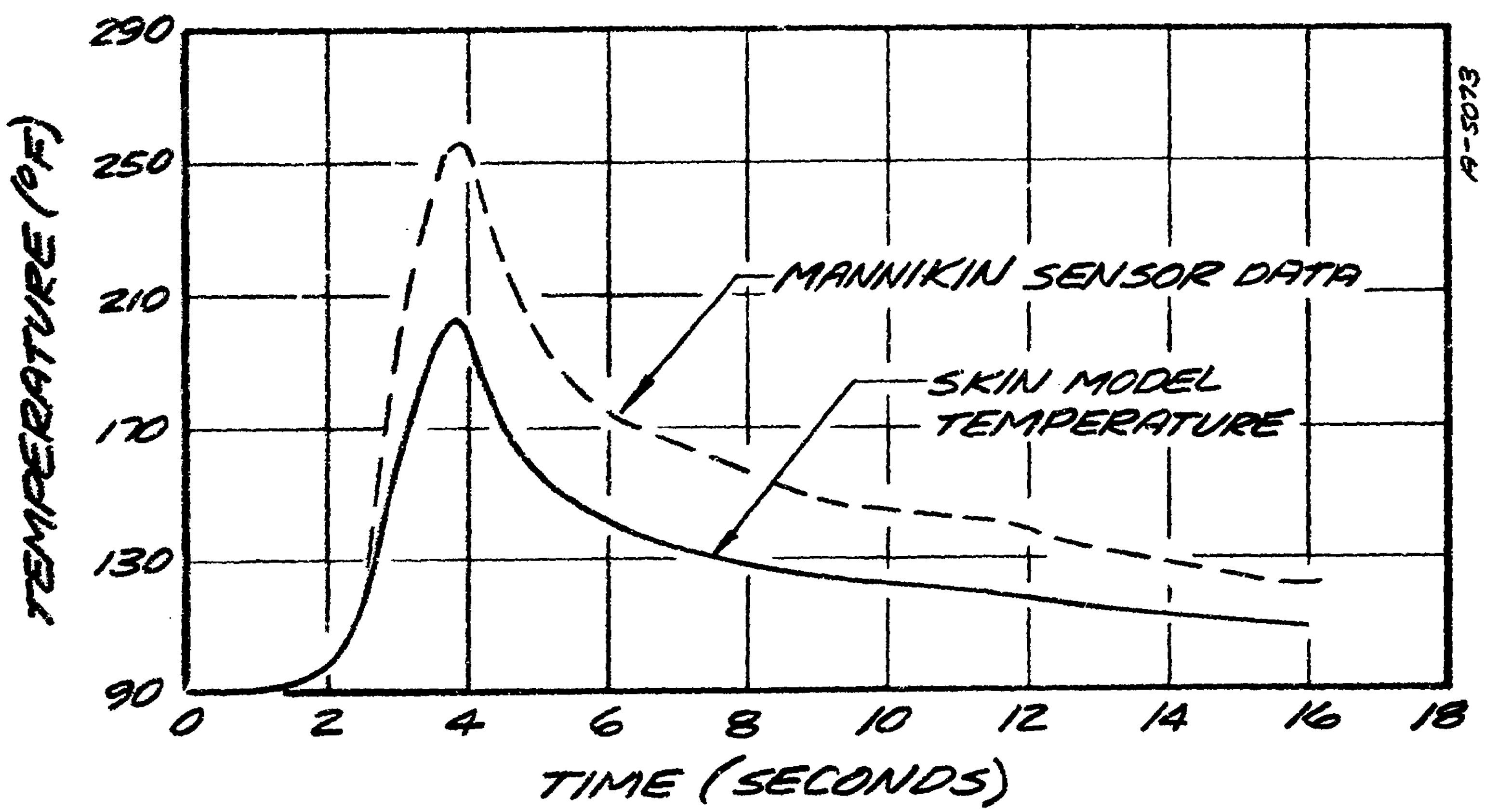


Figure 10. Mannikin Sensor Number 24 - Test Data Left Knee Forward Facing - Class C Burn Ω = 1.0 at 610Ω

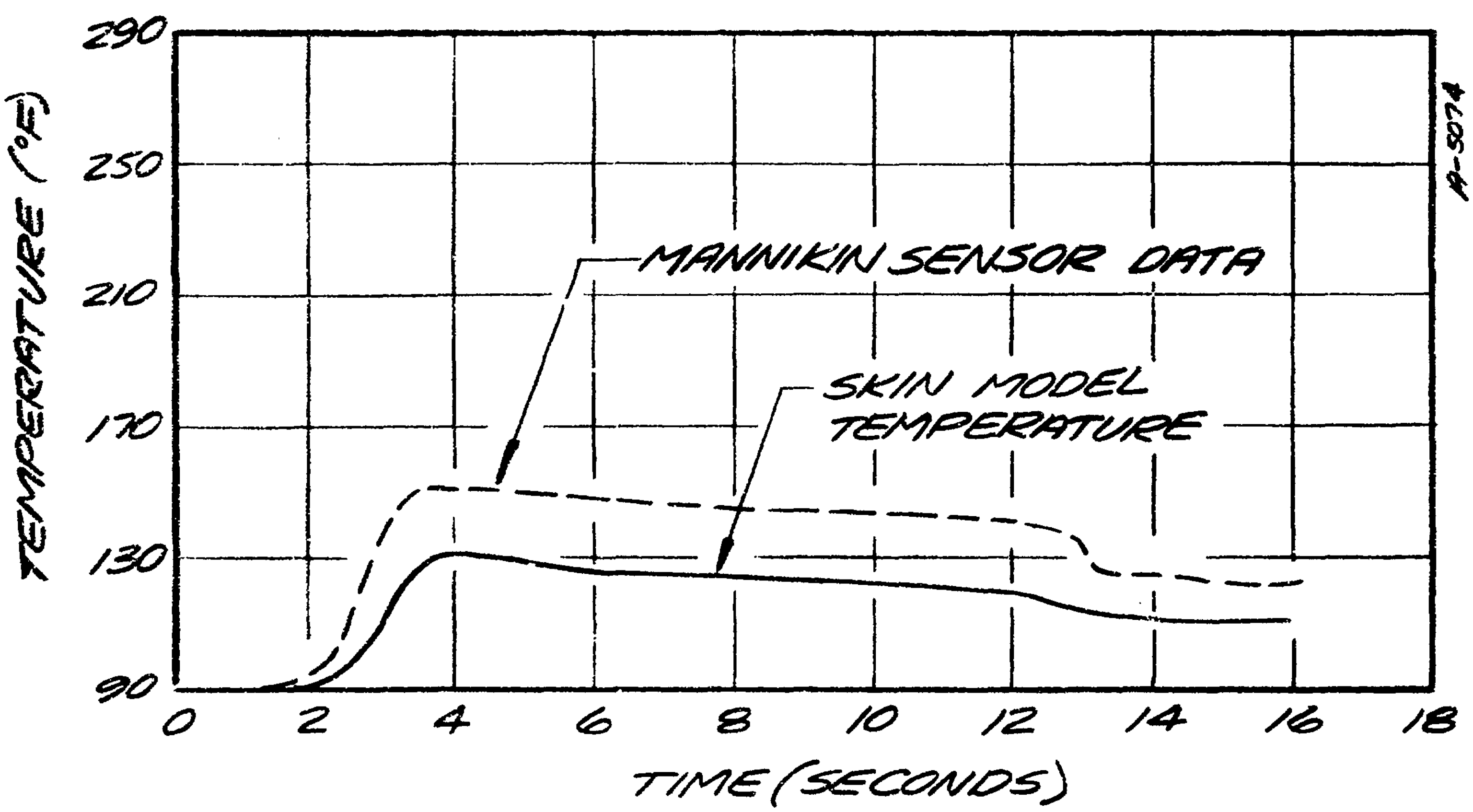


Figure 11. Mannikin Sensor Number 5 - Test Data Left Arm Facing Inward 2-1/2 Inches Above Elbow - Class C Burn $\Omega = 1.0$ at $100\Omega$

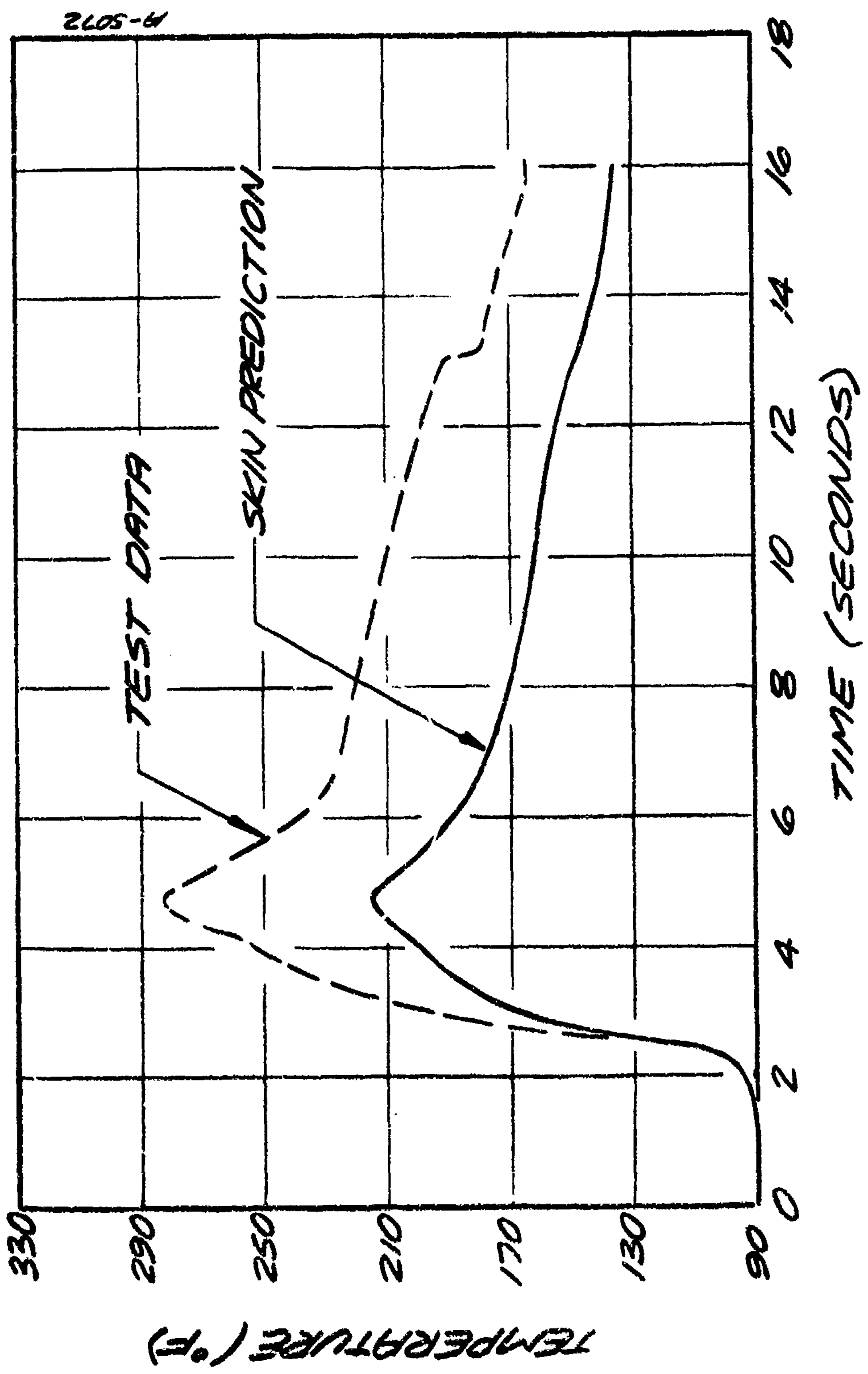


Figure 12. Mannikin Sensor Number 6 - Test Data Left Arm Facing Rear at Point of Elbow - Class D Burn $\Omega = 2.9$ at $2000\mu$

Figure 12.

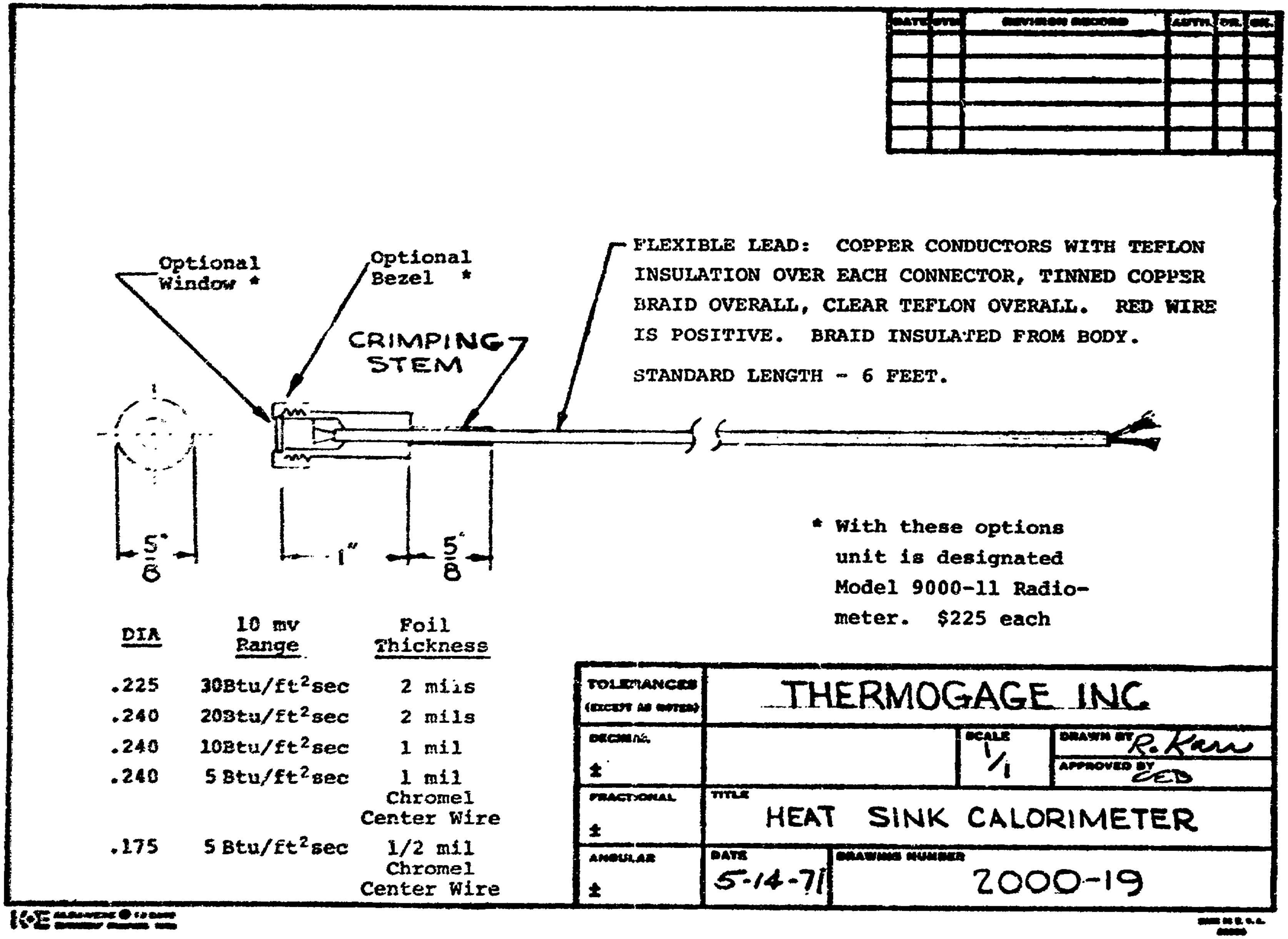


Figure 13. Gardon Gauge Configuration

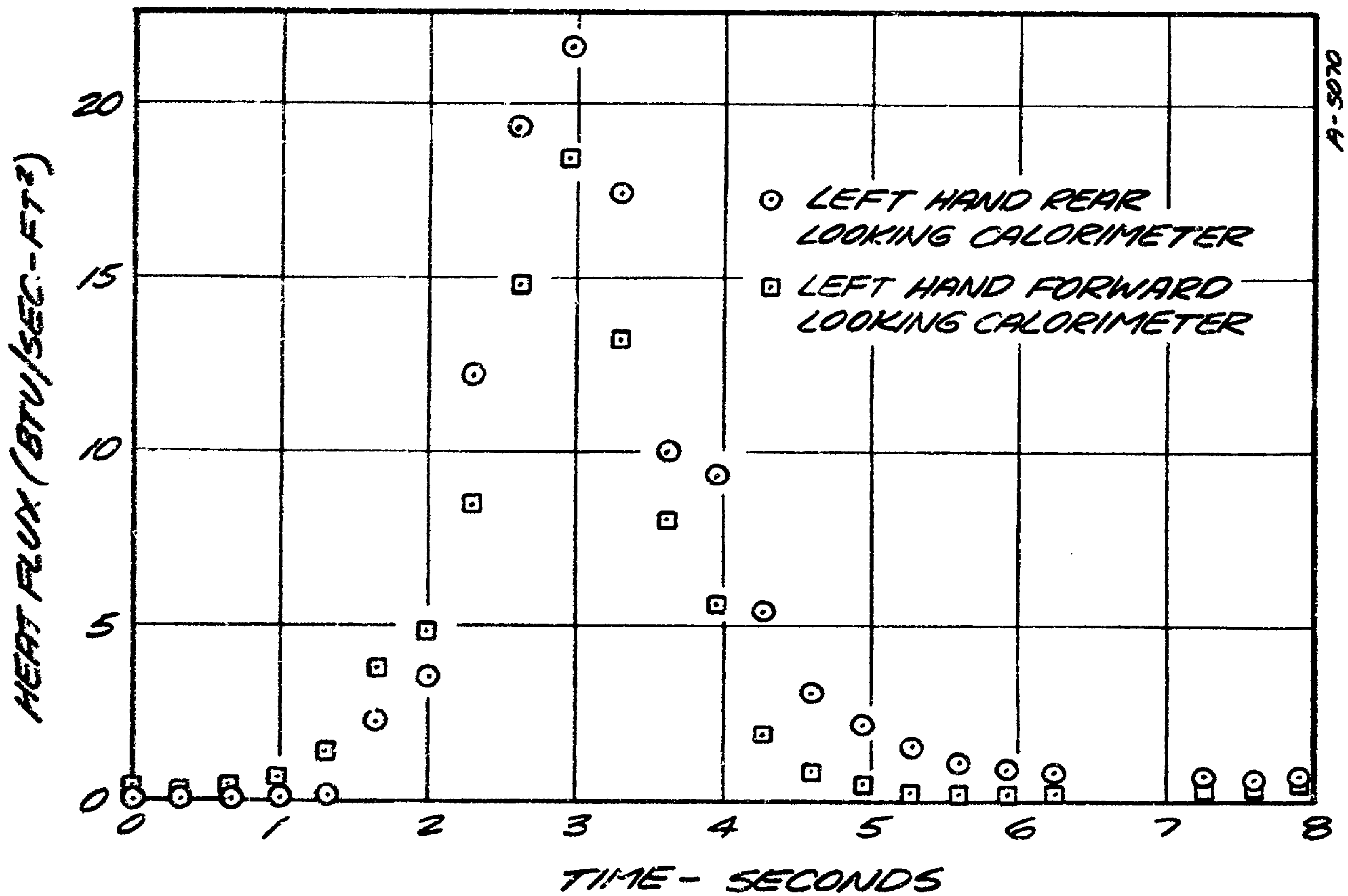


Figure 14. Hand Calorimeter Flame Exposure Flux Time History

radiant energy is received by the sensor from the flame, and that the peak heating from the fire is between 15 and 20 $Btu/ft^2sec$ (4.0 to 5.4 $cal/cm^2sec$).

In addition to the six sensors in the hands there is one heat flux sensor mounted in the back adjacent to a mannikin heat flux sensor, (channel 104). This sensor was to be used to compare heat fluxes measured by the mannikin sensor for further verification of the mannikin measurement approach. As a result of a few tests it was found that the results from this sensor are not consistent. This inconsistency is caused by the fabric coming in contact with the gauge. When this occurs the reading from the sensor is affected. The gardon gauge detects incident heat flux by detecting a temperature difference between the center and edge of a thin foil. When the hot fabric comes in contact with the foil this difference is affected.

The results obtained indicate that in future systems the inclusion of these sensors in the mannikin is not required.

2.2.2.3 Radiant Heat Flux Sensors

Three radiant energy heat flux gauges are used on the mannikin. Two are in the hands and one is on the back adjacent to the back total heat flux gauge. The radiometers were of the design outlined in Figure 13.

These sensors basically consist of a gardon gauge with a window placed in front of the gauge in order to eliminate convective heating.

Typical results from a radiometer and an adjacent hand heat flux gauge are shown in Figure 15. It can be seen from this figure that in general the heat flux from the radiometer is higher than that from the total heat flux sensor. This result indicates a problem with the radiometers. An inspection of the radiometer after a test indicates that the window is covered with soot from the fire. This indicates that very little radiant energy from the fire is incident on the foil of the gardon gauge. It also indicates that the window is heated up to a temperature near that of the fire and energy is radiated from the window to the foil. The angle of view of the radiometer is approximately 130° indicating that energy from only this field of view is received. But the window is very close to the foil providing an angular view as much as 170°. With this knowledge it is expected that in fact the heat flux indicated by the calibrated sensor without a black window would be less than that when the window is black and all the radiant and convective energy is radiated from the window to the foil. This conclusion is further verified by comparing the foil basic calibration constant to that of the foil covered with a window. This difference is approximately 50% with the window foil combination having a lower sensitivity than the bare foil. This result dictates that in future designs the window of the radiometer should be kept clean by blowing gas over its surface or a radiometer should be used in which a window is not required.

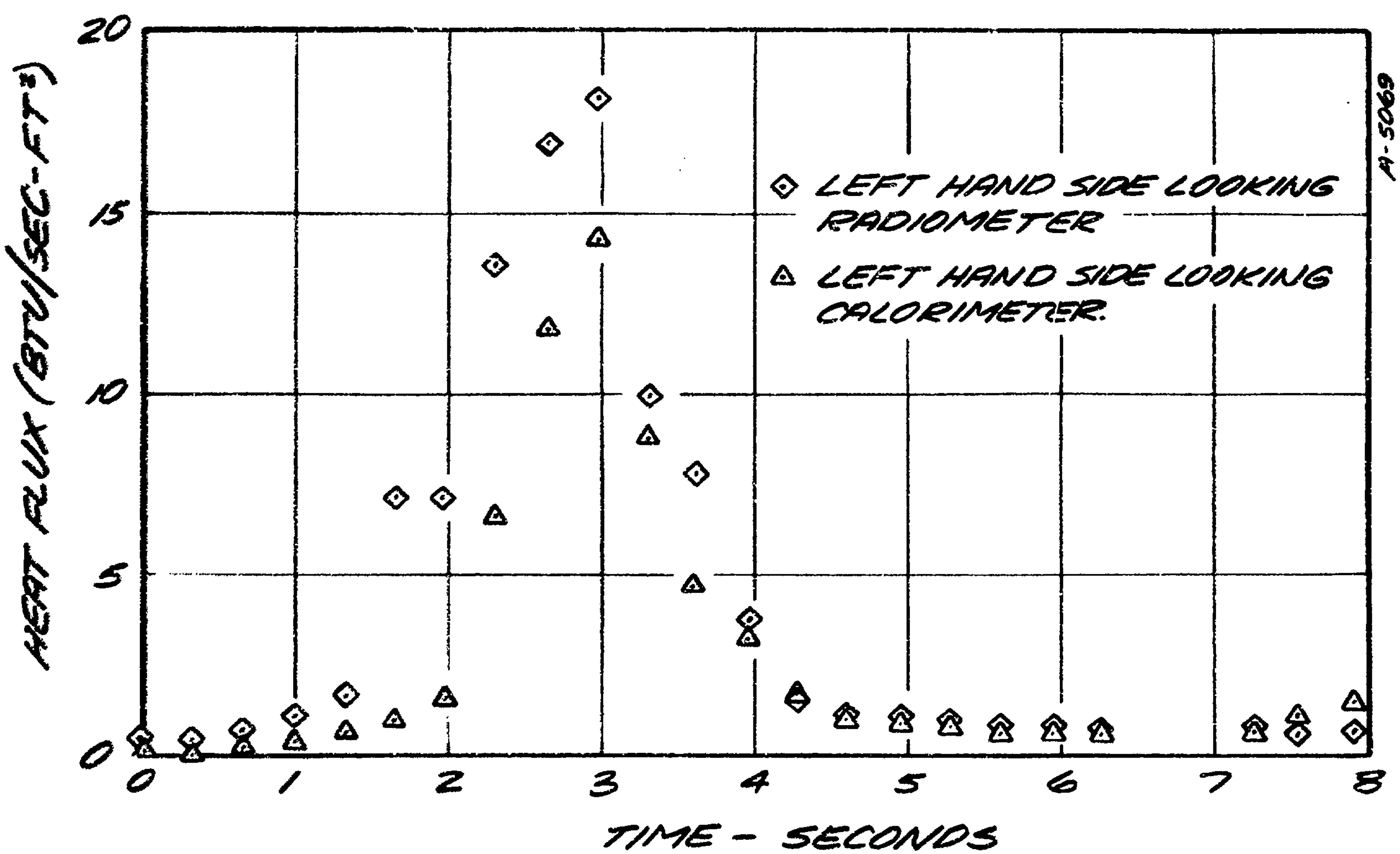


Figure 15. Hand Calorimeter Flame Exposure Heat Flux Time History

The radiometer on the back of the mannikin indicated radiant heat flux levels which were consistent with that obtained with the mannikin sensor. However, two problems do exist with this sensor as outlined below:

- The window tends to be fogged by soot and is quite hard to clean
- When the fabric is in contact with the mannikin sensor the heat fluxes are quite high compared with the radiant heat flux. It is very hard therefore to compare the radiant level with those obtained with the mannikin sensor.

It is suggested that in future systems these sensors be removed and heat flux be measured only with the mannikin sensor.

Mannikin Sensor for Measuring Fire Environment

During a few of the fire tests performed a mannikin sensor was placed in the hand instead of the radiometer. The sensor at this location is adjacent to a total heat flux gardon gauge which allows comparison of the results of two sensors. The results from two separate tests are plotted in Figure 16 and 17. These results show that the mannikin sensor and the gardon gauge provide very similar results with the mannikin sensor probably having a slightly shorter time constant. The results also substantiate the expected accuracy of measurement with the mannikin sensor and suggest that the mannikin sensor can be used as a heat flux sensor with no reduction in the quality of the results obtained. It is therefore suggested in future systems that the gardon gauges be replaced with mannikin sensors in order to reduce the cost of the system.

### 2.2.3 Data Acquisition System (DAS)

The total Mannikin Data Acquisition System consists of two basic components:

- Mannikin Data Acquisition System (MDAS) which is housed in the mannikin.
- Mannikin Support System (MSS).

This total system allows data acquisition during fire exposure with no external wiring required during the total heating cycle. The specification for the total system is contained in the design analysis report along with a complete description of the system functions. Described below are the functions of each unit with a brief description of each system.

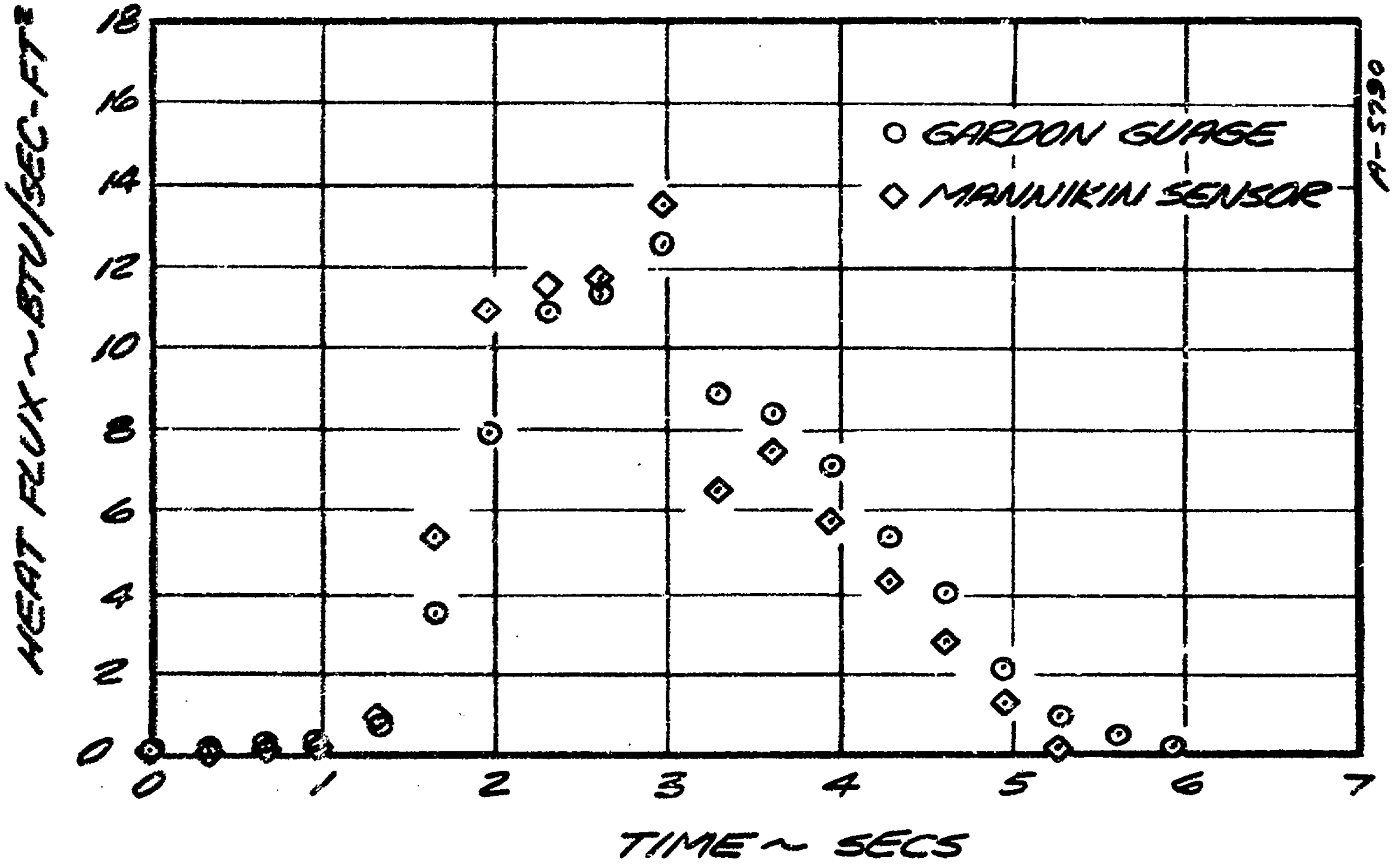


Figure 16. Comparison of Mannikin Sensor with Gardon Heat Flux Gauge Results (Run No. 22)

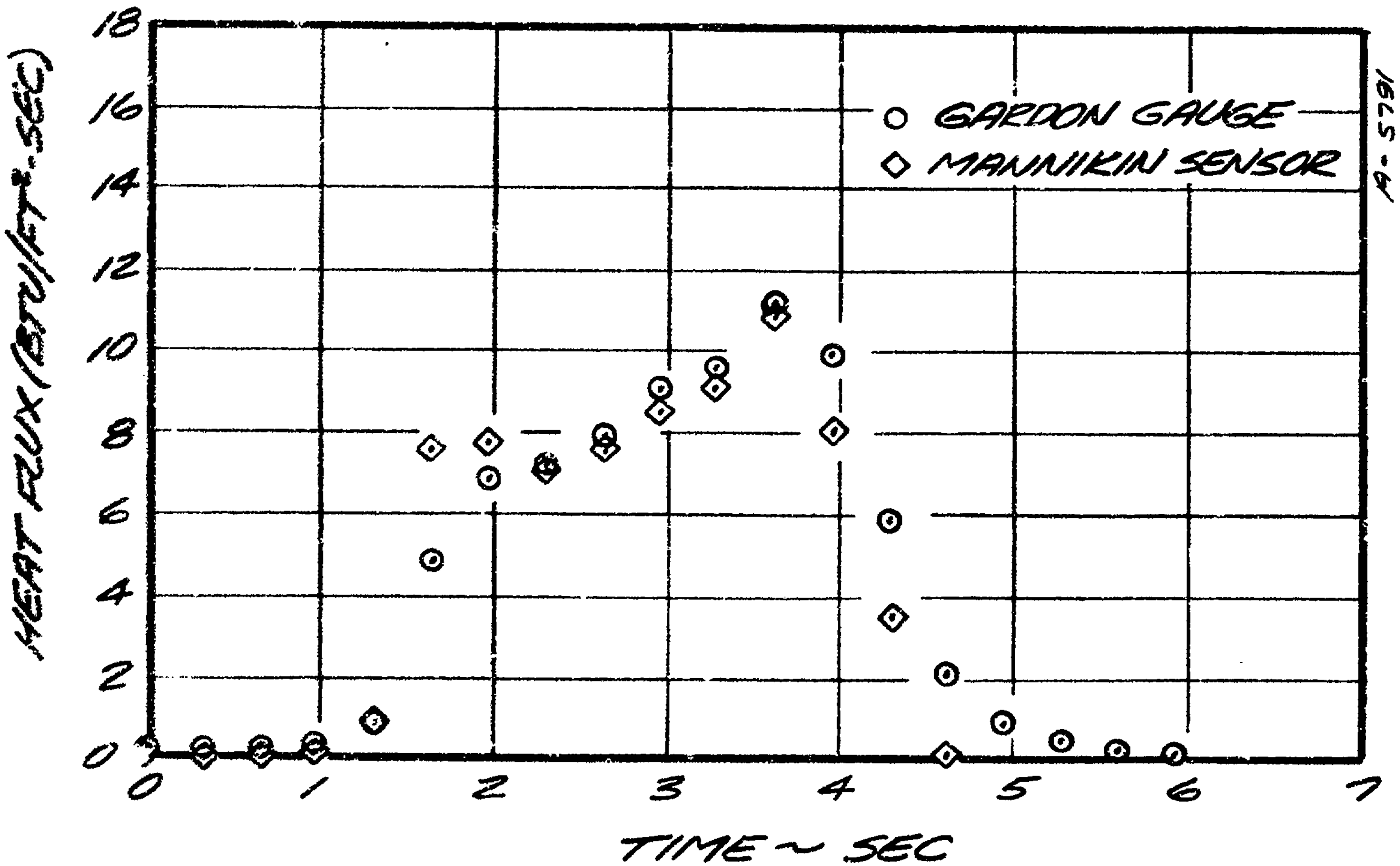


Figure 17. Comparison of Mannikin Sensor with Gardon Heat Flux Gauge Results (Run No. 20)

2.2.3.1 Mannikin Data Acquisition System (MDAS)

The MDAS shown in Figure 18 is housed in the mannikin chest cavity and is approximately 18 x 6 1/2 x 5 3/4 inches. The system has the following basic features:

- 127 channels of input data

  114 copper constantan thermocouples
  10 heat flux gauge inputs
  1 reference thermistor
  1 zero voltage
  1 calibration voltage

- 127 channels scanned every 0.33 seconds
- Self-contained battery operated
- Data storage on a digital cassette tape
- 114 channel reference temperature block.

The system is operated through an umbilical that is connected between the mannikin forehead connector and the MSS. All checkout functions of the MDAS are performed through the MSS using this umbilical. When the system is turned on and ready for data acquisition the umbilical is removed and data acquisition is initiated by removing a lanyard pin mounted in the support bar through the head of the mannikin. At that time, data acquired continuously for a period of 1 1/4 minutes at which time the total power to the system is turned off. (The power is turned off in order to conserve battery power and therefore battery life.)

The battery power is provided by three sets of rechargeable batteries mounted in the mannikin legs. The battery voltage from each of the battery packs is 12, 20, - 20 volts. Each battery is fused in order to limit current and possible catastrophic failure.

The 114 channels reference block is housed within the MDAS enclosure and provides an isothermal area for all thermocouples within the mannikin system. The temperature level of the reference block is determined by a thermistor mounted within the block and a signal is provided to the MDAS for recording on the digital tape. A test program was performed to verify the performance of the reference block and the results of these experiments are described in the Data Analysis Report.

The data for th zero voltage and reference voltage are also provided to the digital tape as data for verification of total system amplification and zero shift. The zero voltage has a shorted input and the constant voltage is provided by a zener diode constant voltage source.

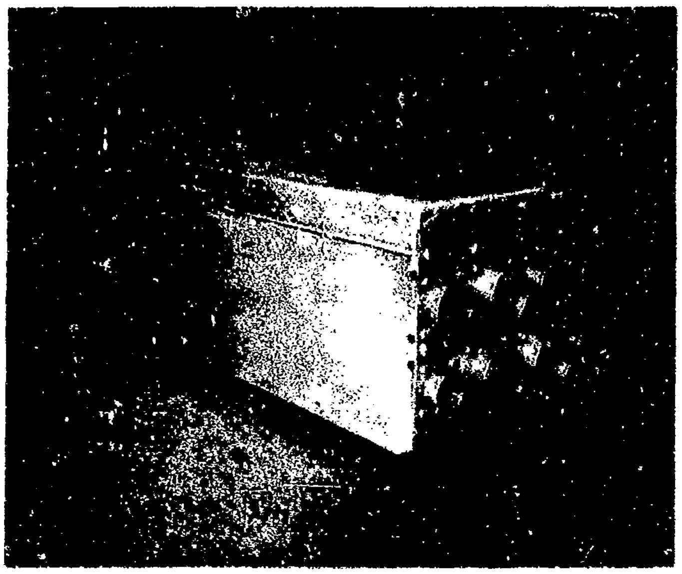

Figure 18. Mannikin Data Acquisition System

All 127 data channels are input to a multiplexer. The output of the multiplexer is then amplified and provided to an A to D converter. The output of the A to D is then recorded on the tape cassette. This operation is continuous until the acquisition time is exceeded at which time the system is shut down.

2.2.3.2 Mannikin Support System (MSS)

The MSS as shown in Figures 19 and 20 consists of two enclosures, one which houses an incremental computer compatible tape deck and the other which houses all the control and transfer functions. The following functions are provided by the MSS.

- MDAS battery charger
- MDAS battery status
- MDAS power control and ready status indicator
- MDAS and MSS cassette control rewind and BOT (beginning of tape)
- Mannikin sensor open circuit detection
- Display of data from a selected channel in real time
- Display of data from cassette tape after test
- Transfer of data from MDAS to MSS to computer compatible tape.

Operation instructions for the system in order to perform the various functions are shown in the checkout instructions. A detailed description of the above functions is included in the Design Analysis Report along with complete circuit diagrams.

2.2.4 Data Reduction

The data reduction package consists of a CDC6600 compatible computer program which reduces the data from the MDAS and MSS into burn damage estimates. Complete details of the computer code are contained in Volume II (User's Manual). Included in this manual are sample input and output data, program flow charts and computer code basic analytic formulation.

A basic process flow diagram for the data reduction package is shown in Figure 21. The following functions are performed within the code;

- Conversion of binary data into counts
- Conversion to engineering units
- Evaluation of data quality
- Computation of surface heat flux from surface temperature-time history

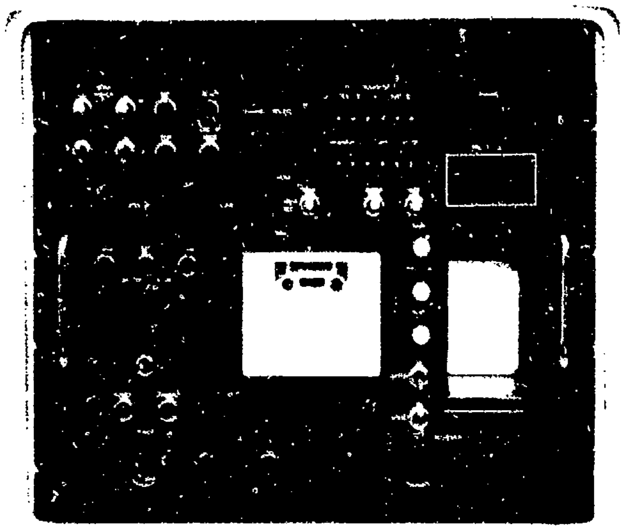

Figure 19. Mannikin Support System Console

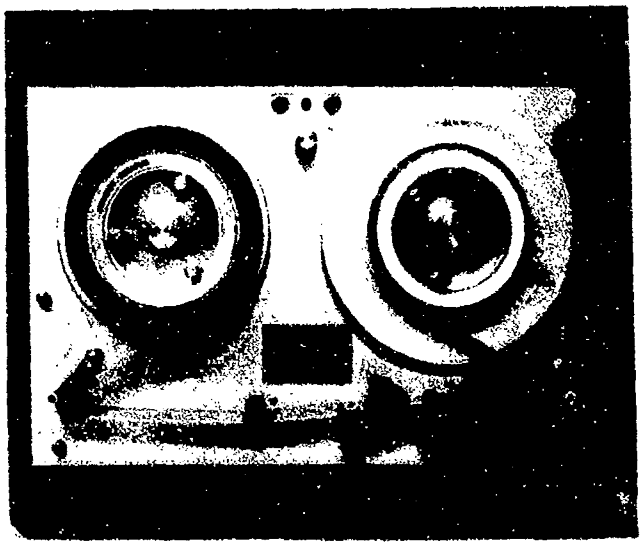

Figure 20. Mannikin Support System Computer
Compatible Tape Deck

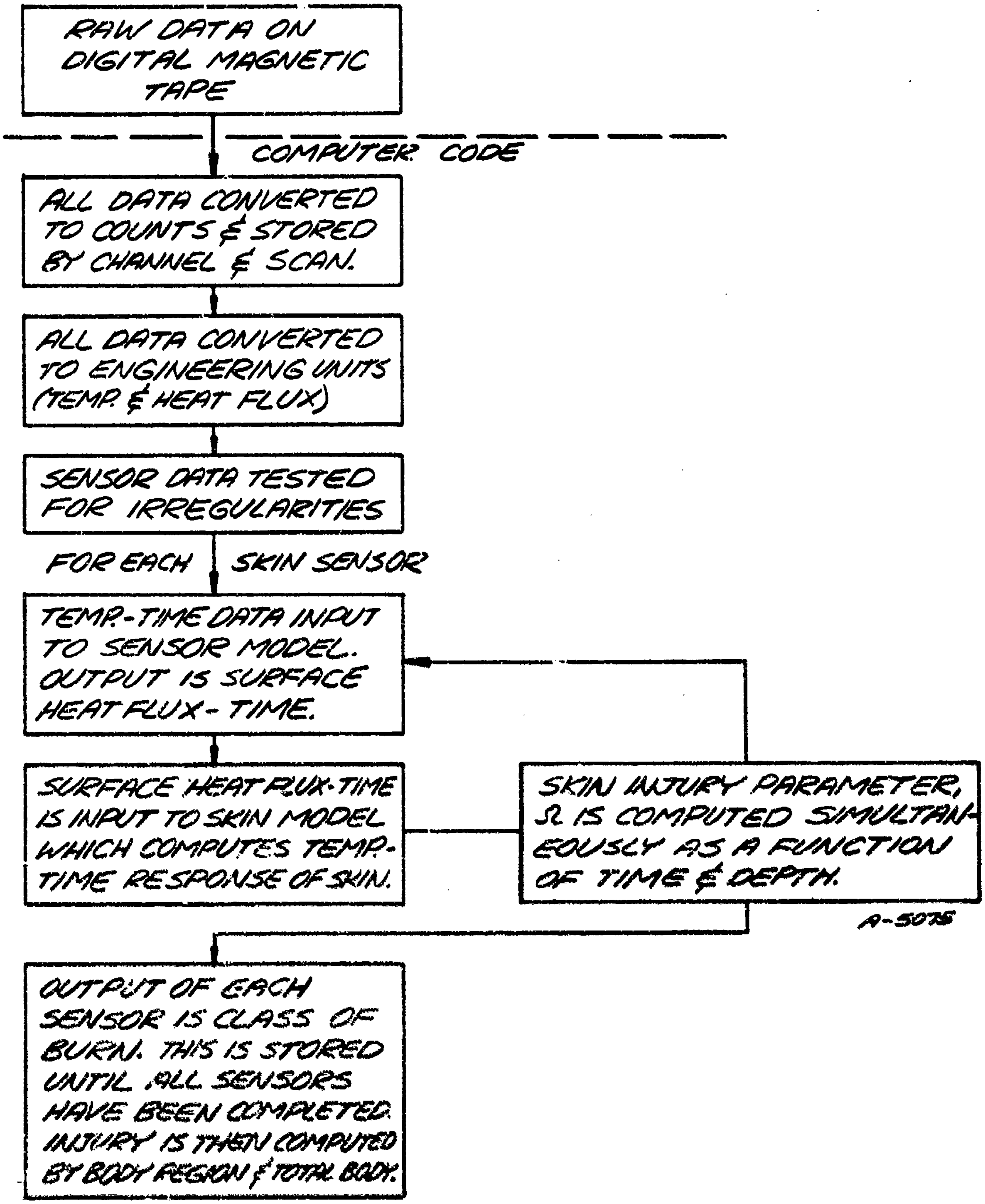


Figure 21. Mannikin Data Reduction Process Flow Diagram

- Computation of skin temperature-time distribution from input of surface heat flux
- Computation of skin injury parameter as a function of depth and time
- Computation of burn injury as a function of sensor location, individual body regions, and total body area (excluding head, hands, and feet).

2.2.4.1 Binary Data Conversion

A special subroutine compatible with the CDC6600 computer has been developed to read the binary data from the MSS and to store these data within the computer. The details of this subroutine are completely described in Volume II.

Each piece of data assocaited with a given channel is provided in a 10 bit binary word. The binary word has a minimum value of 0 counts which corresponds to -1 millivolt sensor maximum output value of 1023 counts which corresponds to +15 millivolts output. Signals which are lower than -1 mv or higher than 15 mv will be recorded as either a 0 or 1023. This scale gives a resolution of approximately 16 microvolts per count. With a sensitivity of 23μ volts per °F for copper-constantan thermocouples, the resolution is approximately 3/4°F. This scheme allows measurement of temperatures between 45°F below the reference block temperature to 620°F above the reference temperature.

2.2.4.2 Conversion to Engineering Units

The data in terms of counts are then converted to engineering units using the following for the various types of sensors:

- Thermocouples -
  Standard NBS thermocouple tables are used to convert millivolts into temperature.
- Heat Flux Gauges -
  Calibration constants for each gauge are used to convert millivolts into heat flux
- Thermistor -
  Reference voltage millivolts signal are used to determine thermistor resistance based on manufacturer's calibration and the reference temperature.

All these data are then provided as output from the computer code.

2.2.4.3 Sensor Heat Flux

The surface heat flux for each sensor is then computed from the measured surface temperature time histories. The analytical model uses measured thermal properties as has been discussed in Section 2.3.2. A one-dimensional analytical model using 10 isothermal finite difference nodes for solution of the Fourier equation is used. The number of nodes was chosen to optimize computer time without a significant reduction in computational accuracy. The thermocouple is assumed to be at a depth of .006 inches below the surface in these calculations. The basic method of solution used is double pass Gaussian elimination.

The analytical model assumes the sensor to be black with all the heat flux absorbed at the sensor surface. The thermal properties of the sensor are assumed to be independent of temperature.

2.2.4.4 Skin Analytical Model and Burn Damage Computation

A detail review of skin thermal properties has been performed and is reported in Reference 87 along with a description of the burn damage model. The analytical computations of temperature in the skin uses basically the same procedures as that used for the heat flux on the surface of the sensor. The basic nodal network is shown in Table 1.

The burn damage model uses the basic approach suggested by Henriques (Reference 37) where tissue damage as a function of temperature is described by a rate process:

$$\frac{d\Omega}{d\theta} = Ce^{-E/rT}$$

Where $d\Omega/d\theta$ is the rate of which damage occurs, C is a rate constant, and E/r is analogous to an activation energy, and T is the temperature.

The burn level determination uses the Stoll Criteria (Reference 76) where $\Omega = 1.0$ at 100 microns is a Class C degree burn, and $\Omega > 0.53$ at 100 microns is a Class B burn. The Stoll criteria has been extended by assuming $\Omega = 1.0$ at any depth represents total irreversible injury to that depth. The justification for selection of this criterion and comparison of analytical predictions to experimental results are shown in Reference 87. Analytical predictions compare well with available data.

2.2.4.4.1 Damage Assessment by Area

As a result of the damage computation performed for each sensor the computer code outputs the level of damage at each sensor location. Sample output of these data is shown in Table 2.

TABLE 1

HUMAN SKIN

ANALYTICAL MODEL

- ONE DIMENSIONAL, 10 - NODE FINITE DIFFERENCE SOLUTION OF FOURIER EQUATION

| NODE | NODE THICKNESS | | DEPTH TO NODE CENTER | $\kappa$ | $\rho C_p$ |
|---|---|---|---|---|---|
| | (Microns) | (Mils) | (Mils) | (cal/ cm sec°c) | (cal/ sec°c |
| 1 | 25 | 1 | 0.5 | $5.5 \cdot 10^{-4}$ | 1.0 |
| 2 | 50 | 2 | 2 | 6.5 | 1.0 |
| 3 | 50 | 2 | Epidermis/Dermis 4 (100 Microns) | 7.5 | 1.0 |
| 4 | 100 | 4 | 7 | 9.0 | 1.0 |
| 5 | 200 | 8 | 13 | 11.0 | 1.0 |
| 6 | 375 | 15 | 24.5 | 12.5 | 1.0 |
| 7 | 500 | 20 | 42 | 13.5 | 1.0 |
| 8 | 650 | 26 | 65 | 13.8 | 1.0 |
| 9 | 100 | 4 | Dermis/Fatty Tissue 80 (2mm) | 14.0 | 1.0 |
| 10 | 2000 | 80 | 122 | 4.0 | 0.5 |

- MODEL ALSO ASSUMES
  * All Incident Flux Absorbed at Surface
  * Adiabatic Back Wall Boundary Condition
  * Surface Emittance of 1.0

TABLE 2

# BURN DAMAGE PREDICTION FOR INDIVIDUAL SENSORS

RUN NUMBER XXX SUIT NUMBER XXX MANIKIN NUMBER 2 DAY 229 OF YEAR 1972

BURN DAMAGE BY SENSOR LOCATION

| SENSOR NO | BODY REGIONS/(PERCENT) | | | | DAMAGE CLASS | OMEGA (100MIC) | OMEGA (2000MIC) | OMEGA=1.0 AT DEPTH (MIC) | STATUS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 203/( 40) | 253/( 60) | 0/( 0) | 0/( 0) | CLASS A | 0.000 | 0.000 | 0.0 | CHECK |
| 2 | 203/( 75) | 253/( 25) | 0/( 0) | 0/( 0) | CLASS A | .000 | 0.000 | 0.0 | CHECK |
| 3 | 253/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS C | 53.819 | .070 | 944.2 | OK |
| 4 | 203/( 50) | 253/( 50) | 0/( 0) | 0/( 0) | CLASS A | 0.000 | 0.000 | 0.0 | OK |
| 5 | 203/( 50) | 253/( 50) | 0/( 0) | 0/( 0) | CLASS B | .640 | 0.000 | 80.1 | OK |
| 6 | 253/( 50) | 251/( 50) | 0/( 0) | 0/( 0) | CLASS C | 9665.139 | .635 | 1774.1 | OK |
| 7 | 201/( 50) | 251/( 50) | 0/( 0) | 0/( 0) | CLASS A | 0.000 | 0.000 | 0.0 | OK |
| 8 | 201/( 50) | 251/( 50) | 0/( 0) | 0/( 0) | CLASS C | 201.776 | .016 | 703.2 | OK |
| 9 | 201/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS C | 3.276 | 0.000 | 224.5 | CHECK |
| 10 | 251/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS A | 0.000 | 0.000 | 0.0 | CHECK |
| 15 | 202/( 50) | 252/( 50) | 0/( 0) | 0/( 0) | CLASS D | 4307.196 | 1.032 | 2032.7 | OK |
| 16 | 202/( 75) | 252/( 25) | 0/( 0) | 0/( 0) | CLASS D | *53883.288 | 266.795 | 0.0 | CHECK |
| 17 | 252/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS A | .118 | 0.000 | 0.0 | OK |
| 18 | 202/( 50) | 252/( 50) | 0/( 0) | 0/( 0) | CLASS D | 277.135 | 1.740 | 2447.4 | CHECK |
| 19 | 202/( 50) | 252/( 50) | 0/( 0) | 0/( 0) | CLASS A | 0.000 | 0.000 | 0.0 | OK |
| 20 | 252/( 50) | 250/( 50) | 0/( 0) | 0/( 0) | CLASS D | *06612.438 | 9.587 | 2949.1 | OK |
| 21 | 202/( 12) | 252/( 12) | 200/( 38) | 250/( 38) | CLASS D | 673.946 | 1.760 | 2454.3 | CHECK |
| 22 | 200/( 65) | 250/( 35) | 0/( 0) | 0/( 0) | CLASS C | 1005.876 | .009 | 612.1 | CHECK |
| 23 | 250/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS D | *28606.586 | 11.603 | 2971.6 | OK |
| 24 | 200/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS D | *15442.579 | 17.248 | 3003.1 | CHECK |
| 29 | 303/( 50) | 353/( 50) | 0/( 0) | 0/( 0) | CLASS A | .010 | 0.000 | 0.0 | OK |
| 30 | 303/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS A | .000 | 0.000 | 0.0 | CHECK |
| 31 | 303/( 50) | 353/( 50) | 0/( 0) | 0/( 0) | CLASS A | .021 | 0.000 | 0.0 | OK |
| 32 | 353/(100) | 0/( 0) | 0/( 0) | 0/( 0) | CLASS C | 49.074 | .030 | 353.6 | OK |
| 33 | 303/( 80) | 353/( 20) | 0/( 0) | 0/( 0) | CLASS C | 38.447 | 0.000 | 385.7 | OK |
| 34 | 301/( 50) | 303/( 50) | 0/( 0) | 0/( 0) | CLASS D | *11475.909 | 11.834 | 2973.5 | CHECK |
| 35 | 301/( 25) | 303/( 25) | 351/( 25) | 353/( 25) | CLASS C | 1.007 | 0.000 | 101.4 | OK |

The mannikin has been divided into 27 body regions and each sensor allocated to this region based on location relative to the region and other sensors. The level of burn for each of these is then output as is shown in Table 3.

The final output from the code is the percentage of each class of burn over the total mannikin surface. Sample output is shown in Table 4. This output also shows the level of fire environment measured by the hand calorimeters.

# TABLE 3
## TOTAL BODY BURN DAMAGE SUMMARY

RUN NUMBER XXX SUIT NUMBER XXX MANIKIN NUMBER 2 DAY 229 OF YEAR 1972

SUMMARY OF BURN DAMAGE BY BODY REGION

| REGION | DESCRIPTION | PERCENT DAMAGE BY CLASS CLASS A | CLASS B | CLASS C | CLASS D | NUMBER OF GOOD SENSORS | NUMBER OF BAD SENSORS |
|---|---|---|---|---|---|---|---|
| 200 | ARM FRONT LOWER RIGHT | 0.0 | 0.0 | 32.0 | 68.0 | 2.03 | 0.00 |
| 202 | ARM FRONT UPPER RIGHT | 21.1 | 0.0 | 0.0 | 78.9 | 2.37 | 0.00 |
| 250 | ARM REAR LOWER RIGHT | 0.0 | 0.0 | 15.7 | 84.3 | 2.23 | 0.00 |
| 252 | ARM REAR UPPER RIGHT | 44.5 | 0.0 | 0.0 | 55.5 | 3.37 | 0.00 |
| 201 | ARM FRONT LOWER LEFT | 25.0 | 0.0 | 75.0 | 0.0 | 2.00 | 0.00 |
| 203 | ARM FRONT UPPER LEFT | 76.7 | 23.3 | 0.0 | 0.0 | 2.15 | 0.00 |
| 251 | ARM REAR LOWER LEFT | 60.0 | 0.0 | 40.0 | 0.0 | 2.50 | 0.00 |
| 253 | ARM REAR UPPER LEFT | 40.3 | 14.9 | 44.8 | 0.0 | 3.35 | 0.00 |
| 300 | LEG FRONT LOWER RIGHT | 23.1 | 35.9 | 28.2 | 12.8 | 3.90 | 0.00 |
| 302 | LEG FRONT UPPER RIGHT | 32.3 | 18.3 | 43.3 | 6.1 | 8.20 | 0.00 |
| 350 | LEG REAR LOWER RIGHT | 40.4 | 11.5 | 38.5 | 9.6 | 5.20 | 0.00 |
| 352 | LEG REAR UPPER RIGHT | 21.7 | 26.1 | 26.1 | 26.1 | 5.75 | 0.00 |
| 301 | LEG FRONT LOWER LEFT | 42.8 | 0.0 | 46.0 | 11.4 | 4.40 | 0.00 |
| 303 | LEG FRONT UPPER LEFT | 45.4 | 9.0 | 20.1 | 6.5 | 7.65 | 0.00 |
| 351 | LEG REAR LOWER LEFT | [illegible] | 18.9 | 42.4 | 0.0 | 4.00 | 0.00 |
| 353 | LEG REAR UPPER LEFT | [illegible] | [illegible] | 43.0 | 0.0 | [illegible] | 0.00 |
| [illegible] | TORSO FRONT LOWER RIGHT | [illegible] | 0.0 | [illegible] | [illegible] | 9.15 | 0.00 |
| [illegible] | TORSO FRONT LOWER LEFT | [illegible] | [illegible] | [illegible] | [illegible] | 9.10 | [illegible] |
| [illegible] | TORSO FRONT UPPER RIGHT | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | TORSO FRONT UPPER LEFT | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | TORSO BACK LOWER RIGHT | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | TORSO BACK LOWER LEFT | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | TORSO BACK UPPER RIGHT | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | TORSO BACK UPPER LEFT | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE 4

BURN DAMAGE FOR 27 BODY REGIONS

RUN NUMBER 888 SUIT NUMBER XXX MANIKIN NUMBER 2 DAY 229 OF YEAR 1972

SUMMARY OF BURN DAMAGE TO THE TOTAL BODY

(EXPOSURE LIMITED TO 78 PERCENT OF BODY SURFACE)

| PERCENTAGE OF BODY SURFACE BURN DAMAGE BY CLASS | BASED ON TOTAL BODY AREA | TOTAL AREA COVERED BY FLIGHT SUIT |
|---|---|---|
| % AREA A NO DAMAGE (DAMAGE LESS THAN 0.53 AT 100 MICRONS) | 39.68 | 50.88 |
| % AREA B DAMAGE BETWEEN 0.53 AND 1.0 AT 100 MICRONS) | 5.47 | 7.02 |
| % AREA C DAMAGE GREATER THAN 1.0 BETWEEN 100 AND 2000 MICRONS) | 21.21 | 27.19 |
| % AREA D DAMAGE GREATER THAN 1.0 AT 2000 MICRONS) | 11.63 | 14.91 |
| TOTAL | 78.00 | 100.00 |
| TOTAL CLASS C AND D | 32.84 | 42.11 |

THE [illegible] ARE BASED ON THE EXPOSURE BY OPERATIONAL SENSORS OF 78.00 PERCENT OF THE BODY SURFACE AREA.

[illegible] 22 PERCENT OF BODY SURFACE (HEAD, FEET, HANDS) IS NOT COVERED BY SENSORS.

SUMMARY OF HEAT FLUX DATA

TOTAL INTEGRATED HEATING

BTU/FT2 (CAL/CM2)

| | LEFT HAND | RIGHT HAND | BACK |
|---|---|---|---|
| [illegible] | [illegible] | 38.636 ( 10.616) | 19.313 ( 5.234) |
| [illegible] | [illegible] | 35.560 ( 9.637) | |
| [illegible] | [illegible] | 50.017 ( 13.555) | |
| [illegible] | [illegible] | 41.338 ( 11.203) | |
| [illegible] | [illegible] | 51.[illegible] ( 13.[illegible]) | 14.651 ( 3.970) |

AVERAGE FIRE LEVEL

(AVERAGE OF ALL HAND CALORIMETERS)

38.082 ( 10.320)

Best Available Copy

# SECTION 3

## RESULTS AND RECOMMENDATIONS

The mannikins have undergone two sets of field tests prior to final delivery. A total of 24 three-second fire exposures were experienced by the two mannikins.

The mannikins are fulfilling their anticipated function with ruggedness and quick turn-around proven.

The data processing system has not only provided more accurate burn damage assessment than heat sensitive tape installation on mannikins, but has revealed, through the time-temperature profiles available, more information about the nature and characteristics of the fire environment.

Future developments should include:

1) Data Acquisition System -

   a) The data acquisition system should be modified from using the internal cassette recorder in the MDAS to a solid core, variable clock rate system. This system will increase the versatility of the mannikin so that long or short term test exposures can be made. The total number of data points will be constant but the data rate could be varied from the current 375 data points per second (approximately continuous) to incremental scans up to one scan per every thirty seconds which would record test data in excess of an hour.

   b) The system should be modified to provide real time data transfer directly to computer compatible tape via hard line thus giving the capability for non-hazardous fixed mannikin testing over extended periods of time.

2) Computer Code -

   The computer code should be modified to add the capability for analyzing thermal fatigue and long term (over 12 second exposure) skin damage.

3) Instrumentation -

As a result of the data obtained with the mannikin instrumentation the following recommendations are suggested:

- The heat flux gauge and radiometer used on the back of the mannikin should not be used in subsequent systems. The mannikin sensor has proven itself as a reliable heat flux measurement device.
- The gauges mounted in the hands should be replaced with mannikin sensors for improved time response and reduced costs.
- A gas purged radiant energy sensor should be utilized for further use in mannikin measurement of radiant heat flux during fire exposure.
- Measurements of fire environment as a function of mannikin surface location should be performed to evaluate the intensity of heating as a function of position on the mannikin.
- The instrumentation should be extended to include sensors on the head, hands and feet.

4) Mannikin Maintenance and Support -

The recommended mannikin maintenance log and trouble reporting system should be implemented so that problem areas can be readily identified and design improvement can be implemented.

In addition, a normal refurbishment program should be implemented so that all elements, (MDAS, MSS, Instrumentation, and Mannikin) can be refurbished on a regular and timely basis.

With the above modifications, the already proven advantages of the instrumented mannikin could be extended to cover almost every conceivable application of thermal testing of clothing from short term hazardous environment to long term fixed position, thermal fatigue studies.